INFLUENCE OF THE ION IRRADIATION DURING LOW-ENERGY NITROGEN ION ASSISTED DEPOSITION OF WURTZITIC GALLIUM NITRIDE FILMS ON SAPPHIRE

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In the last ten years, growth of thin GaN films on various substrates like sapphire or silicon carbide has attained vast growing attention due to the excellent optical and electronic properties of this semiconducting material. The most established GaN preparation methods include metal-organic vapour phase epitaxy (MOVPE), molecular beam epitaxy (MBE) with nitrogen atom sources, or halide vapour phase epitaxy (HVPE). Due to kinetic restrictions reducing the adatom mobility, MBE-grown GaN is still of minor crystalline quality in comparison to MOVPE-GaN, when deposited on lattice-mismatched substrates. HVPE allows to grow GaN at high deposition rates at the cost of crystalline quality, but films prepared by this method are possible candidates as substrates for homoepitaxial growth of GaN. A possibility to overcome kinetic restrictions during the growth process is to use the method of low-energy ion beam assisted deposition (IBAD). This method resembles MBE, but with the important difference that here nitrogen is delivered to the growing film in form of hyperthermal nitrogen ions with kinetic energies of several 10 to several 100 eV. In this paper it will be shown how wurtzitic GaN films of high crystalline quality can be grown on sapphire by IBAD. The influence of the kinetic energy of the nitrogen ions on the epitaxial growth of GaN is investigated.

Wurtzitic GaN films were grown by irradiating gallium condensating on a sapphire substrate with hyperthermal nitrogen ions in high vacuum. Gallium was evaporated by a conventional effusion cell. Two ion sources were used to obtain nitrogen ions with energies in the range of 25 to 250 eV. The first one was a hollow-anode constricted glow discharge source and the second one was a Kaufman-type ion source with a two-grid acceleration system. The substrate temperature was kept constant at 750 °C. All GaN films were directly deposited on the bare sapphire substrate without substrate nitridation or pre-deposition of a low-temperature buffer layer. Typical growth parameters are summarized in table 1.

effusion cell temperature	950 to 1050 °C
gallium flux	1.0 to 6.0 $\times 10^{14}$ atoms cm^{-2} s^{-1}
growth rate	up to 0.1 nm/s
substrate temperature	750 °C
film thickness	up to 1750 nm
ion energy	25 - 250 eV
ion current density	20 - 100 µA cm^{-2}
ion to gallium atom ratio	0.3 – 6.5

Table 1: Growth parameters for ion beam assisted deposition of GaN films.

The structure of the films was characterized by X-ray diffraction (XRD) using both, symmetrical and asymmetrical reflections. Applying Rutherford backscattering spectrometry (RBS) under channeling conditions along two different channels, the depth distribution of defects could be investigated. The surface topography was examined by atomic force microscopy (AFM). In order to obtain information on the morphology of the films, transmission electron microscopy (TEM) of cross-sectionally prepared samples was conducted.

The results of the investigations show, that wurtzitic GaN films grown with IBAD are epitaxial, as proved by XRD pole-figure measurements, and of good crystalline quality. The use of nitrogen ions with high ion energies leads to a lattice expansion and a high mosaicity of crystallites. Additionally, high ion energies or a high ion flux with respect to the gallium flux favours the formation of the zincblende-phase of GaN. This behaviour is vice-versa to MBE growth of GaN, where zincblende-GaN is formed under gallium-rich growth conditions.
With a low ion energy of less than 25 eV the GaN films show better crystalline quality than with higher energies, but may still contain a distinct amount of zincblende GaN.
Increasing the ion to gallium atom ratio in the beginning of the growth process by continually raising the gallium flux was found to be a key step resulting in pure wurtzitic GaN films of the highest crystalline quality and the lowest surface roughness in this paper. Rocking curve FWHMs of less than 20 min, minimum RBS backscattering yields of less than 2% (see figure 1), and RMS surface roughnesses of less than 2 nm could be obtained.

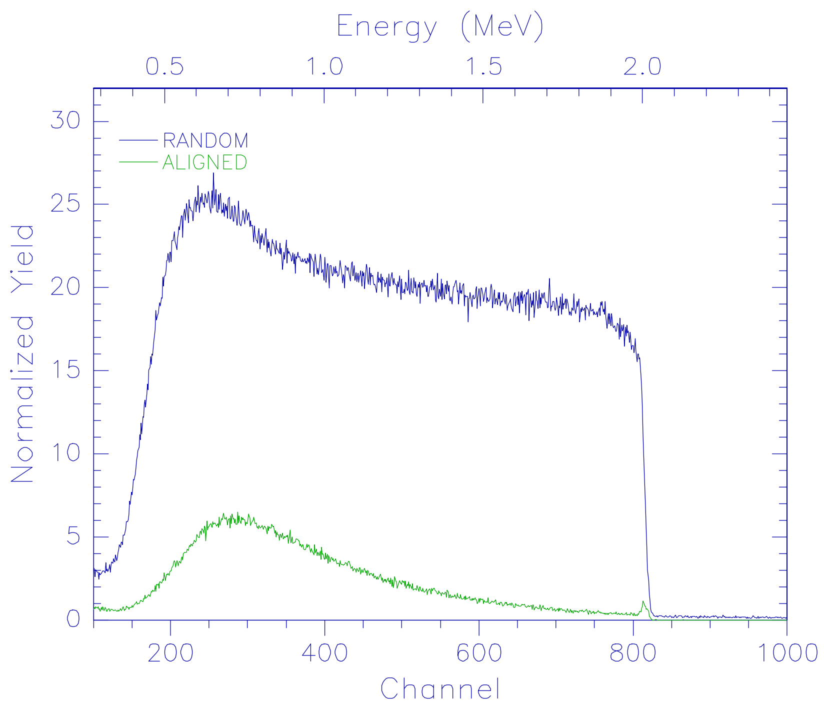

Fig. 1: RBS channeling measurement along the [001] direction of a GaN film prepared by ion beam assisted deposition. The minimum backscattering yield was found to be 2%.

The results are discussed within the picture of ion assisted epitaxy, where the ion energy must be chosen in a way that it lies between two limiting energies. The low limit is, that the ion energy must be high enough to create ion-induced defects in the surface layer to stimulate surface processes. The upper limit is given by the energy where defects are created below the surface layer and lead to residual damage deteriorating the crystalline quality. The influence of the second IBAD parameter, the ion to gallium atom ratio is also discussed, especially in comparison with gallium-rich/nitrogen-rich MBE growth.